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A frequency agile 94 GHz pulse-doppler radar with dual polarisation capability

by

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ABSTRACT

The design of a coherent, frequency agile 94 GHz radar frontend is reported. This radar includes features like pulse to pulse frequency agility in steps of 10 MHz within a bandwidth of 400 MHz and fixed or staggered PRF in a wide range between 1 and 50 kHz. The output power of 16 Watt and the antenna gain of 45 dB result in an effective radiated power of 89 dBm. The polarisation of the transmitted wave is switchable from pulse to pulse either from RHC to LHC or from horizontal to vertical. This depends on the kind of primary feed horn used for the 300 mm cassegrain antenna. Co- and cross polarized echo signals are received and processed by two separate but identical receiver channels. Line scanning with a rate of 20 scans per second is done by a flat rotating mirror.

INTRODUCTION

Besides of the frequency range around 35 GHz the band at 94 GHz offers another atmospheric window with low attenuation. This high frequency allows the application of very small antennas maintaining a narrow beamwidth. Therefore, systems at these frequencies are ideally suited for a variety of applications where at the same time small size, low weight and high directivity or high lateral resolution are required, e.g. in missile seeker applications.

In this case the radar often works under severe clutter conditions; on the other hand, a high lateral and range resolution is necessary to determine important target features.

To measure signatures of different targets and clutters, a versatile measurement radar system was developed. In the following table, the most important features of this radar are listed:

Frequency	: 94 GHz
Agility	: 400 MHz in steps of 10 MHz
Effective radiated power	: 89 dBm
Transmit polarisation	: switchable from pulse to pulse, RHC/LHC or horizontal/vertical by choice of the antenna feed horn
Range resolution	: 375 mm
Pulse width	: 70 ns
Pulse repetition frequency	: 1 to 50 kHz (fixed or staggered)
Receiver	: 2 channels for co- and cross polarisation
Peak to valley ratio	: 78 dB/Hz
Antenna system	: 300 mm Cassegrain system, 0.7 degree beam width, flat rotating mirror for line scanning
Radar control	: operators keyboard or computer interface

PRINCIPLE OF OPERATION

A simplified block diagram of the radar is shown in Fig. 1. As a frequency reference, a 160 MHz cristal oscillator is used. From its signal all required frequencies, even the PRF, are derived by multiplication, division and up- or downconversion.

In the mm-wave range, the first part of frequency processing is done at half the operating frequency allowing the application of more standard and reliable components and semiconductor devices.

A 46.24 GHz VCO is phase locked to the reference source employing a harmonic mixer. In order to achieve very high spectral purity, the Gunn-diode VCO is additionally cavity stabilized /1/. Its output power is fed into the varactor upconverters for both the transmitter synchronisation and the local oscillator branch. The low frequency input signals of the upconverters provide the frequency agility and a constant frequency offset between transmitter and local oscillator frequencies which, at this stage, amounts to half the receiver IF frequency. The output signals of both branches are locking two second harmonic mode oscillators at their fundamental frequencies /2/. In this way, active frequency doubling with more than 3 dB gain is achieved.

One of these fundamental/second harmonic mode oscillators acts directly as local oscillator for the two receiver channels while the other serves as injection locking source of the IMPATT power amplifier.

IMPATT POWER AMPLIFIER

For this radar application, a high degree of coherency and phase stability is required. Therefore, a transmitter with low phase error is necessary. Since the frequency chirp of pulsed oscillators in the free running state is converted to phase chirp in the injection locked state, two main conditions are derived from the requirements mentioned before:

A low locking gain (e.g. 10 dB) and a high locking range (e.g. I GHz) and low chirp of all oscillators in the free running state are essential.

Therefore, the IMPATT power amplifier is composed of a three stage injection locked IMPATT-oscillator chain /3/ shown in Fig. 2 followed by a 4 oscillator hybrid power combiner /4/ shown in Fig. 3. The low power stage of the IMPATT oscillator chain (Fig. 2) employs a 150 mW single drift IMPATT-diode initially optimized as CW-device. This diode is preheated by a DC current of 200 mA. An additional current pulse of 400 mA is required to produce output power. This mode of operation reduces the frequency chirp caused by temperature rise of the device significantly.

For the medium power stage a special designed I.5 W single drift pulse IMPATT-diode is used. This diode has a significant current-frequency dependence that enables chirp compensation by current pulse shaping (see bias pulse modulator).

A double drift diode delivering 12 W peak is used in the higher power stage. It needs a pulse current of roughly II A. Bias pulse shaping is absolutely required for proper operation of this design, but unfortunately it has less influence to its inherent frequency chirp. However, the thereby caused phase chirp is compensated by predestortion the phase chirp of the medium power stage.

In this way, a maximum phase ripple of only +3 degree is achieved. The output power of the IMPATT oscillator chain, reduced to 6,4 W by circuit losses, serves as injection power for a four oscillator hybrid power combiner, shown as blockdiagramm in Fig 3.

Four IMPATT-oscillators are powercombined by four 3 dB/90^{0} hybrid couplers as shown in the center of Fig. 3. Additionally, the symmetry of this arrangement is used to provide switching of the output ports without any loss of output power. This is done by using a PIN-diode switch in the input path of the power combiner. If the injection signal is fed to port 1', the combined (or sum) power appears at port 2" while the difference power comes out at port 2' and vice versa.

Both output ports are connected to the two transmit/receive diplexers in the antenna frontend, where each port is associated to one polarisation. The combiner is matched by means of broadband isocirculators at the input ports (inserted between PIN-diode switch and combiner) as well as the output port.

Because the IMPATT-diodes of the oscillators O_I to O_4 shown in Fig. 3 are operated in a mode similar to a saturated reflexion amplifier, their contribution to the overall phase chirp is as good as neglectable.

Output power per diode is about 7,5 Watt peak, the combiner output power at the ports 2' or 2" amounts to 28 Watt peak.

Circuit losses as well as the insertion loss of the PIN-diode switch reduce the synchronisation power available for the combiner to about 4 Watt peak. The output power at the antenne feed was measured as 16 Watt peak. This is caused by the losses of the isocirculators, turnstile coupler, T/R-diplexers e.t.c.

RECEIVER FRONTEND

A more detailed block diagram of this part of the radar is given in Fig. 4. Directly connected to the circular waveguide antenne feed horn, a turnstile junction serves as polarization coupler separating an arbitrarily polarized incident wave into two rectangular waveguide outputs representing the LHC and RHC polarized components. A circulator serving as T/R diplexer, a PIN-diode STC and a balanced mixer are connected to each of these ports. Depending on the required transmit polarization, the output power of the IMPATT amplifier is fed to one of these circulators.

In order to reduce losses in the receiver paths, the complete arrangement is built into a compact block using E-plane techniques for circulators, STCs and mixers /5/. The turnstile coupler was scaled down from lower frequency versions /6/. The E-plane circulators /7/ show a reduced bandwidth compared to H-plane circulators; their set-up, however, is very simple and easy to fabricate.

Mixer and STC are realized in finline technique /5/ integrated on a single substrate for each channel. The STC provides a maximum attenuation of about 30 dB. The conversion loss of each channel (including circulator, STC, mixer) amounts to 9.5 dB, the SSB system noise figure (including IF contribution) is 13 dB. The mechanical dimensions are 75 x 60 x 20 mm.

IF SIGNAL PROCESSING

Both co- and cross-polarized signals are processed in two identical IF amplifiers. Behind a low noise IF preamplifier (NF = 1,5 dB) an IF-STC switch using a dual gate FET is implemented. The additional dynamic range of 40 dB gives an overall STC dynamic range of 70 dB. The slope of both the RF and IF STC is digitally controlled by means of a PROM. Thus the STC slope is accurate and temperature stable.

A range gate with a dynamic-range of 70 dB as well as a precision step attenuator is implemented in the 640 MHz IF path. After filtering, the IF-signal is downconverted to 160 MHz. At this frequency, a logarithmic amplifier with a dynamic-range of 60 dB and a phase-constant limited are implemented. This limiting amplifier has a phase error of less than 8 degrees over 60 dB of input dynamic range. Coherent detection is accomplished using I-Q phase detectors for both channels as well as an I-Q detector for the differential phase of the two channels.

MECHANICAL CONSTRUCTION AND SCANNER

The millimeter wave parts of the radar are assembled on a separate thermally insulated chassis which is temperature controlled by means of heating and fan-cooling. This chassis, together with the first IF circuitry, the pulse power supply of the transmitter and the antenna are mounted in the radar head as shown in Fig. 5. To this head, a mechanical scanner with a rotating flat mirror is connected. The flat mirror is metallized on both sides. Thus, with a rotation rate of 600 turns per minute, a scan rate of 20 scans per second is achieved over a operative scan angle of +30°. The antenna and the scanner are covered with a housing including a low loss radom (0.3 dB).

The radar head is connected via cable to a 19 inch rack containing the second IF level circuitry, the necessary signal processing components, the basic frequency processing and the basic power supply. The Radar can be operated either by a keybord type operation board or under computer control. The complete radar equipment is shown in Fig. 6.

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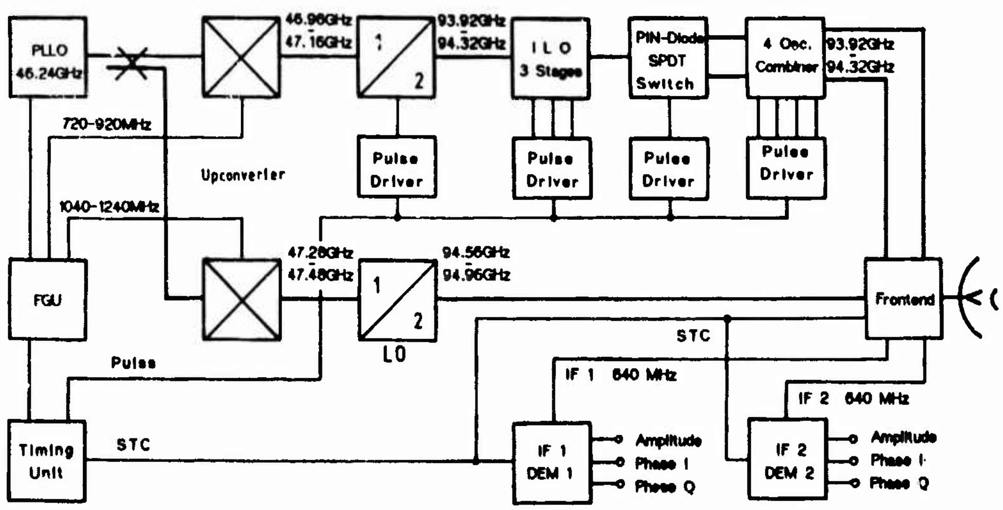

Fig. 1 Simplified Block Diagram of the Radar

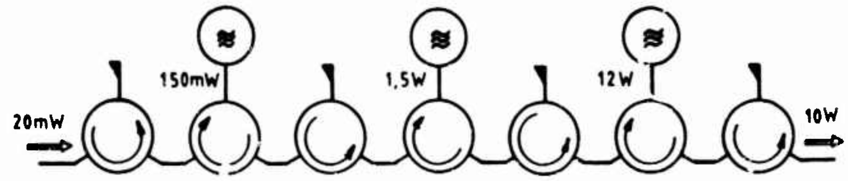

Fig. 2 Three Stage Injection Locked Oscillator Chain

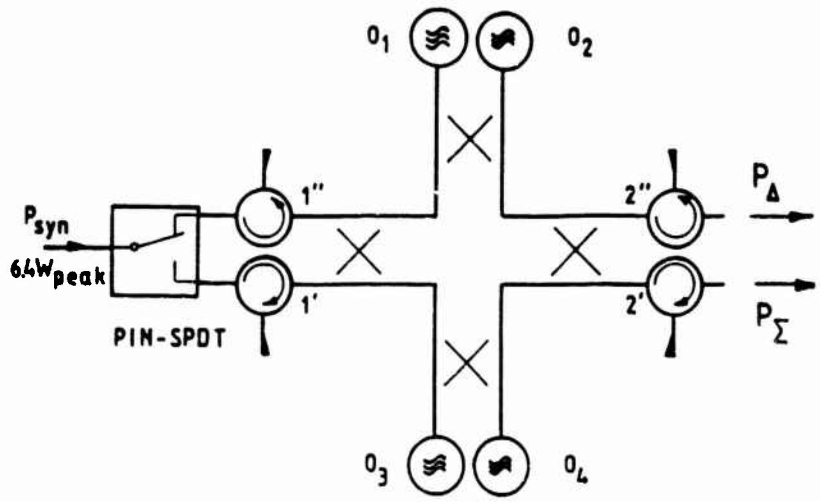

Fig. 3 4 Oscillator Combiner used as High Power Polarisation Switch

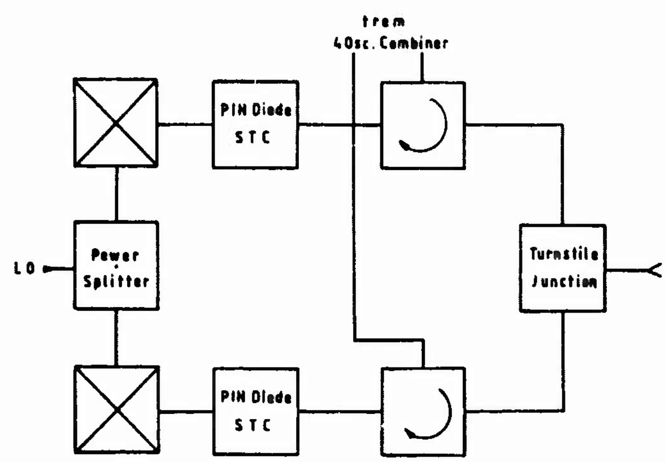

Fig. 4 Receiver Frontend

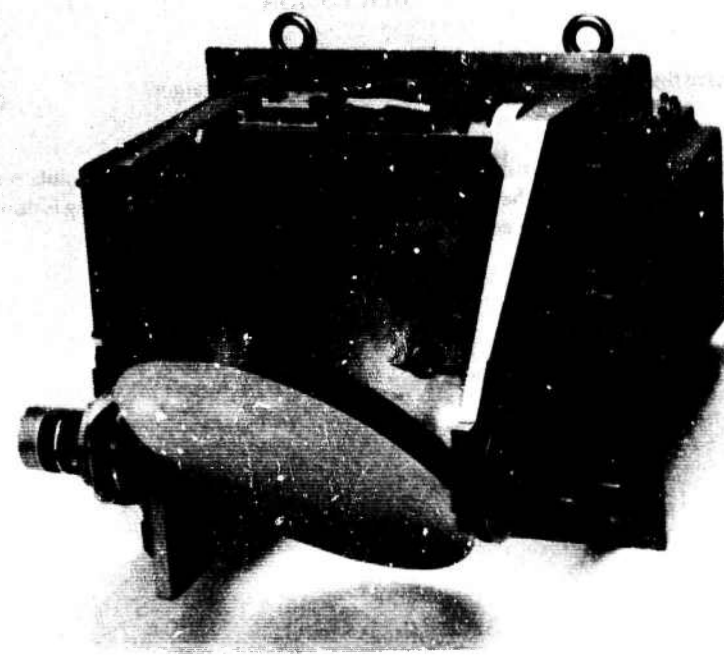

Fig. 5 Radar Head

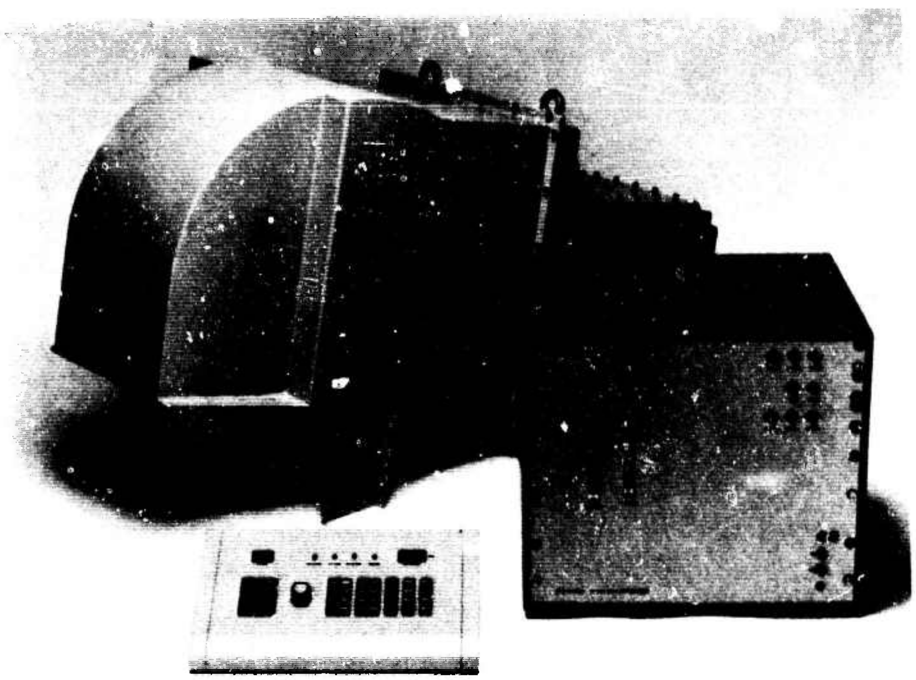

Fig. 6 The Complete Radar Equipment

DISCUSSION

G.A.van der Spek

Can the system derive the scattering matrix of each resolution cell of a target?

Author's Reply

Yes, it is able to determine the complex scattering matrix in a cell of 15m with an absolute resolution of 38cm. The accuracy to determine the distance of the object is typical for pulse radars. Processing is done by the group of Mr. Baars, FGAN-FHP, Wachtberg Werthhoven — see buss. card.